Effect of Sampling Density
on
Trend-Surface Analysis
of
Copper Concentrations
in the
Bonanza District, Colorado

by

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ABSTRACT

A reduced number of data points is used to calculate positive residuals and trend surfaces for two variations of a system used by Professor Pride of the Department of Geology and Mineralogy at The Ohio State University to summarize geochemical data from the Bonanza caldera, Saguache County, Colorado. The intent was to test whether a reduced number of data stations might yield reliable information on the relation of copper concentrations to the geology of the Bonanza area.

Two areas of mineralization and associated hydrothermal alteration probably related to the emplacement of ring-type intrusives have been identified along the northeastern and southeastern margins of the Bonanza caldera. It appears that anomalous copper concentrations may be related to mineralization within the caldera.

INTRODUCTION

The purpose of this investigation is to determine the effect of variations in sampling and sample location on the trend-surface analysis of selected geochemical data from the Bonanza mineral district of Colorado (Pride and Hasenohr, 1983); the variations included using one-half and one-quarter the number of original sample locations. The aim is to determine whether a system that uses a reduced number of data points will obtain results that are similar to those reached by Pride and Hasenohr (1983) who related residual geochemical anomalies to the geology of the Bonanza area and to locations of metals in the district.

The Bonanza mineral district is located in the northeastern portion of the San Juan volcanic field and on the western margin of the Rio Grande rift system in southwestern Colorado (Fig. 1).

ACKNOWLEDGEMENTS

Thanks are due to Jeff Lucius, a graduate student of geophysics at The Ohio State University, who aided in this investigation by writing job control language for the Surface II program and by answering various questions concerning the computer system. The guidance of Charles E. Corbato' and Douglas E. Pride, Professors of Geology and Mineralogy at The Ohio State University, is gratefully acknowledged. Their data, references, and computer programs are greatly appreciated.

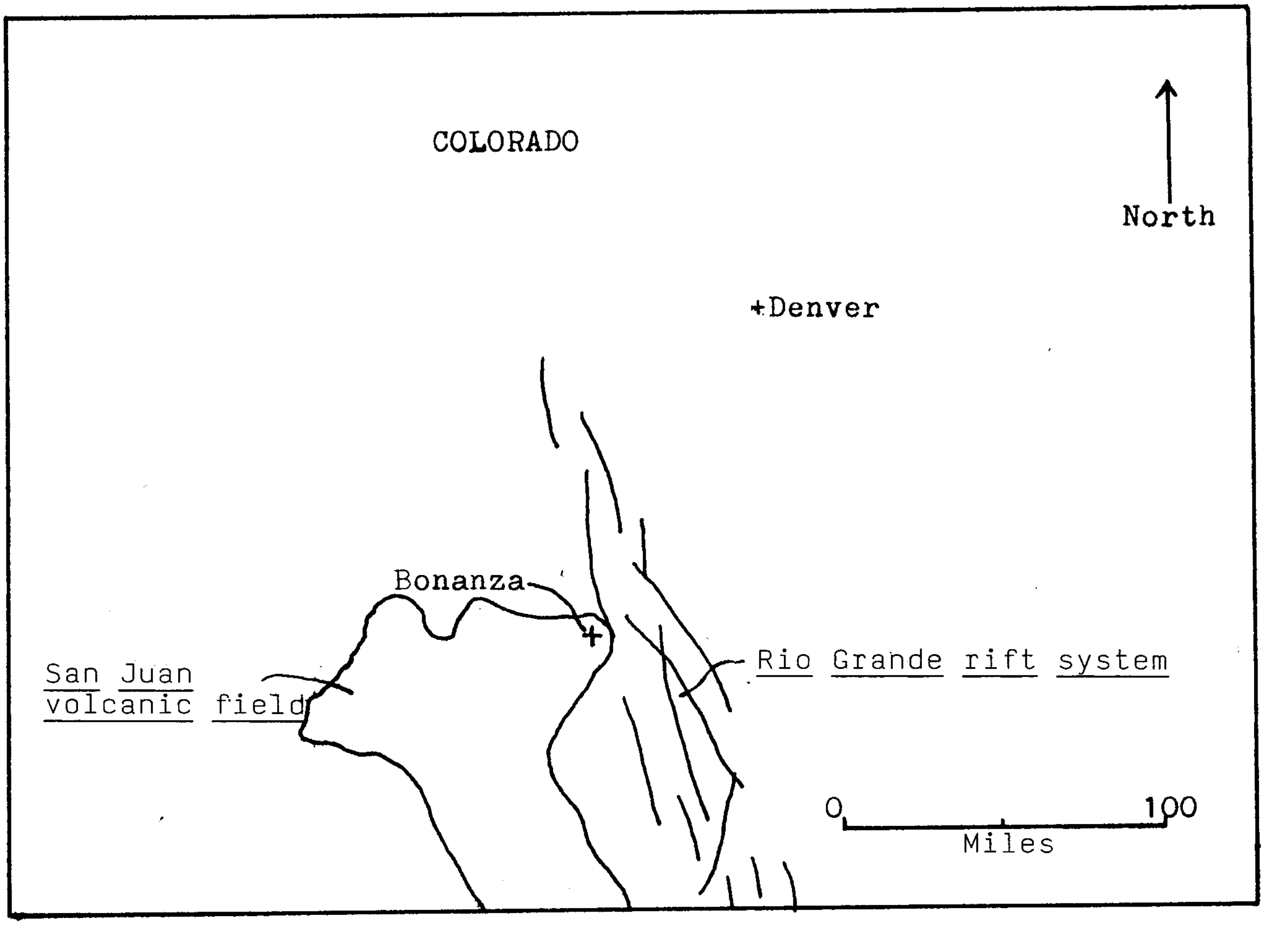

Figure 1. Location map of Bonanza mineral district and its relation to the San Juan volcanic field and the Rio Grande rift system. (After Steven and Lipman (1976) and Varga and Smith (1984))

GENERAL GEOLOGY OF THE SAN JUAN REGION

A number of intrusive bodies penetrating the surrounding extrusive igneous rocks makes the geology of the San Juan region complex. According to Steven and Lipman (1976), calderas formed in the San Juan region above a batholith. Extrusive and pyroclastic eruptions emptied parts of the underlying batholithic chamber causing many of the overlying shield volcanoes to collapse, producing calderas. Upward movement of the magma resulted in localized resurgence of some calderas soon after collapse, and a regional uplift of the batholith resulted in a tensile condition causing the formation of grabens and faults. This broader uplift was focused especially in the eastern portion of the San Juan volcanic field. Collapse and resurgence of calderas in the San Juan volcanic field led to ring-fractures, faults, and fissures that were to focus hydrothermal alteration and mineralization (Steven and Lipman, 1976).

There may be as many as 18 calderas in the San Juan volcanic field, with the Bonanza caldera located in the eastern part of the field being the oldest of these structures (Steven and Lipman, 1976). The majority of the volcanic rocks found in the San Juan area are early to middle Oligocene in age.

GEOLOGY OF THE BONANZA AREA

The stratigraphy of the Bonanza mineral district, as described by Burbank (1932) and Varga and Smith (1984), consists of an irregular surface of Precambrian basement overlain unconformably by 5000 feet of Paleozoic limestones, arkoses, and shales. This sequence is capped unconformably by a thick suite of extrusive volcanic rocks that ranges in composition from andesite to rhyolite. The suite of volcanic rocks is composed of flows and breccias of the Rawley Andesite, which are overlain by the Bonanza Tuff and an upper andesitic sequence (Varga and Smith, 1984). The Bonanza Tuff is zoned into a lower dacite and an upper rhyolite. A series of intrusives, oriented in a manner similar to the ring fractures of the caldera, are found

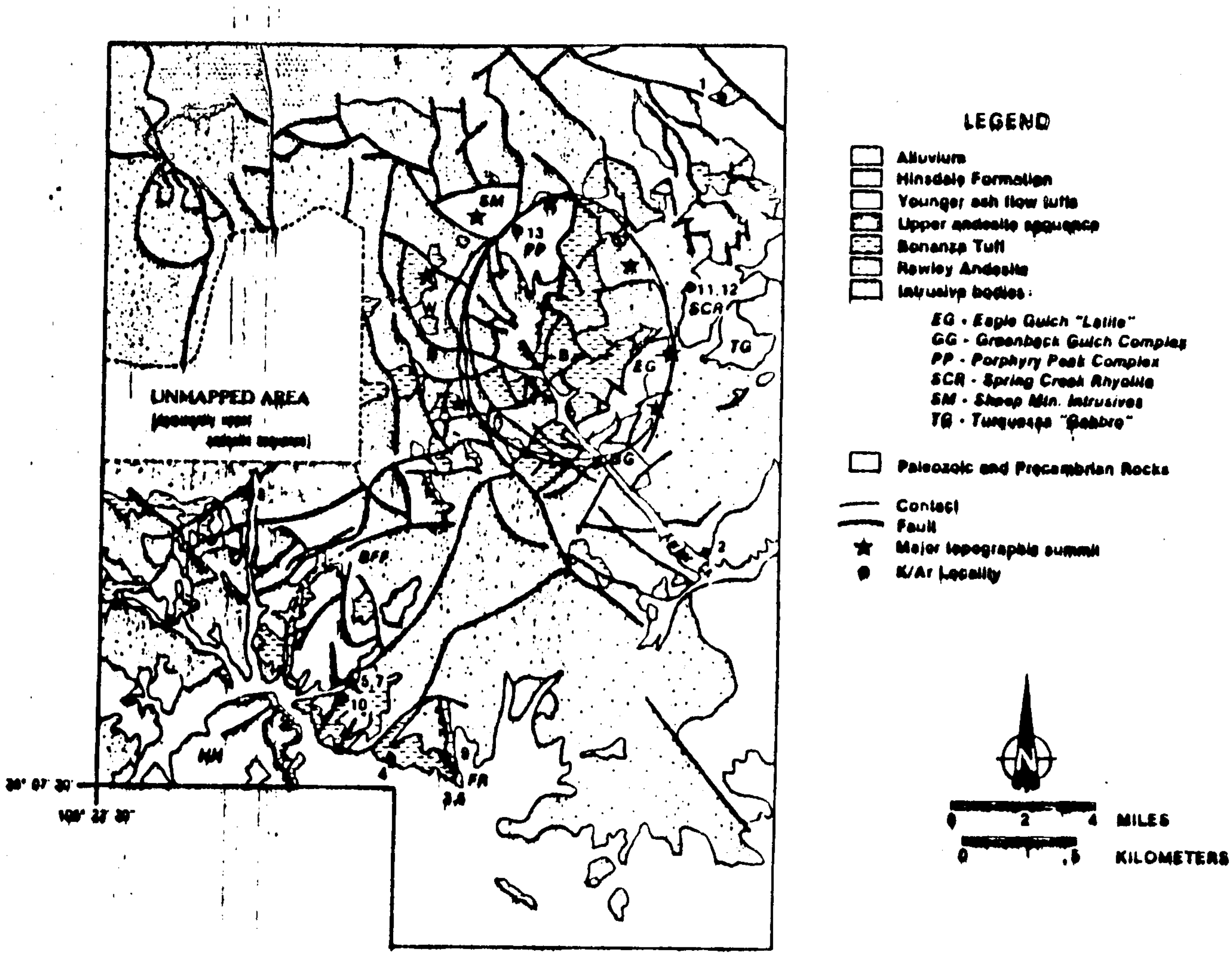

Figure 2. Geological map of the area around the Bonanza caldera (shown as an oval in the northeastern part of the map). (After Varga and Smith, 1984).

cutting the extrusive volcanic sequences. These intrusives form stocks, domes, dikes, and sills in the Bonanza area, and they are commonly present near the margin of the caldera. Of the intrusive suite, the Porphyry Peak complex, the Eagle Gulch "Latite", and the Green Gulch complex outcrop within the Bonanza caldera, while the Sheep Mountain intrusives, the Turquessa "Gabbro", and the Spring Creek Rhyolite outcrop just outside of the caldera (Fig. 2).

The region encompassing the Bonanza mining district has been hypothesized as a caldera by several researchers, including Cook (1960) and Karig (1965). Karig used gravimetric geophysical data to hypothesize a caldera centered approximately on the mining town of Bonanza.

The Bonanza caldera is postulated (Steven and Lipman, 1976) to have formed from collapse, and later, from resurgence related to the general evolution of the San Juan volcanic field. The structure at Bonanza formed over a slowly rising satellite body to a large batholithic body beneath the San Juan volcanic field. A different explanation is presented by Varga and Smith (1984) who point out that the formation of the Bonanza caldera and its later silicic intrusions marked the inception of the Rio Grande rift system. According to Varga and Smith (1984), the Bonanza caldera is more closely related to northern calderas such as Mount Aetna and Grizzley Peak, which also are located on the western margins of the Rio Grande rift system, than to calderas of the San Juan volcanic field.

Based on differences in mineralization and alteration, Burbank (1932) divided the Bonanza area into a northern and a southern mineral district. The northern district, located in the northeastern part of the caldera, is characterized by ores of mainly zinc, copper, silver, and lead, and mineralization is localized within fissures and faults. The mineralization in the southeastern part of the caldera is more widespread and is characterized mainly as silver ores.

DATA SAMPLING METHODS

The data used in this investigation is a portion of the 230 square kilometer area of soil samples that were used in the study of Pride and Hasenohr (1983), who related mineralization in the Bonanza mineral district to the geology of the Bonanza caldera. Pride and Hasenohr used 1566 soil samples for their study of the Bonanza area; this investigation used 1140 of these samples. A rectangular area of approximately uniform (400 meters) spaced samples was selected to simplify computer manipulation (Figure 3). The area included the two mineral districts of the Bonanza caldera.

Details concerning soil sample collection and chemical analyses may be found in Pride and Hasenohr (1983).

The basic data from the Bonanza area has been sampled in several ways. Pride placed a coded limit of between 2-1000 ppm on the copper values to limit the effects of extremely high concentrations and to account for missing data, such as samples that were missing from the grid. The coded limit prevented potential problems in computer manipulations and subsequently in the misinterpretations of the results. The 1140 sampling points, which are called the initial set, form a rectangle with 30 columns and 38 rows. Program NOSORT, listed in Appendix A, calculates the 4th, 5th, and 6th degree trend surfaces and residual values for copper of these stations.

The first procedure for sampling the data, consisting of

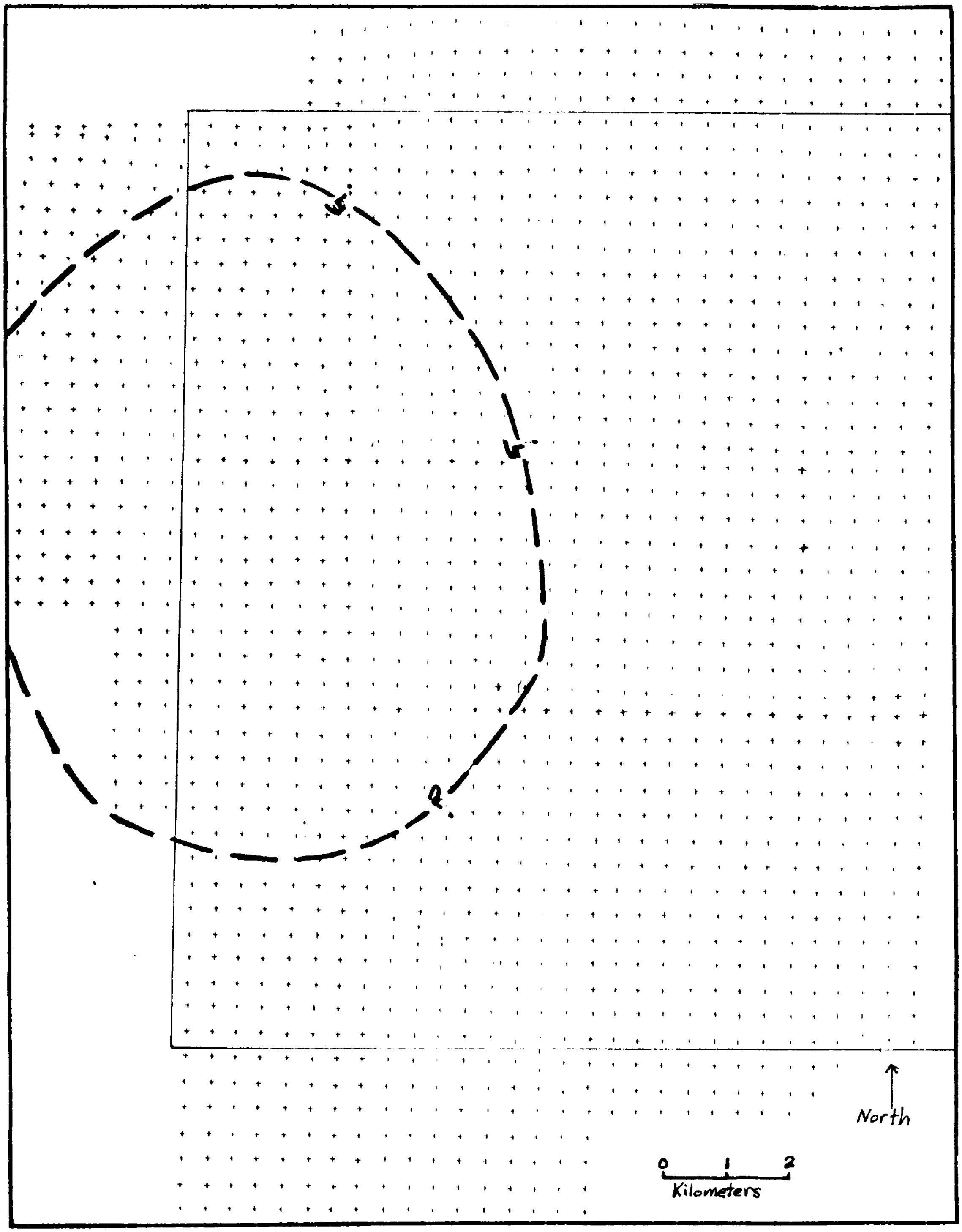

Figure 3. Sample locations, Bonanza area, are shown as a rectangular array of 30 columns and 38 rows within the inner rectangle. Approximate boundary of the caldera is shown by dashed lines. After Pride (personal comm.).

selecting 570 data points, gives subsets labelled sample 1A and sample 1B (Figure 4). Program NOSORT (Appendix A) was changed to derive subsets 1A and 1B. Samples 2A and 2B, consisting of 285 data points each, have been handled in a manner similar to the first subsets.

The 4th, 5th, and 6th degree trend surfaces and residual values for the initial set, and for variations 1 and 2, were plotted and contoured individually using the Surface II plotting program (Sampson, 1975). A sample Surface II program is listed in Appendix B, and information describing parameters, commands, and the Surface II plotting package can be found in Sampson (1975).

The Surface II plotting package is useful because it can be used to attenuate the extreme highs and lows in the data that are a result of the analytical technique (Pride and Hasenohr, 1983). The Surface II package 'dampens' fluctuations by calculating a second grid upon which contours are drawn. Anomalous highs and trends for copper that can be seen on the residual and trend surface contoured maps, may then be related to the geology of the Bonanza region.

An overview of trend surface and positive residual values is necessary to understand their value for interpreting the chemical data in terms of the geology of the Bonanza region. The trend surface, as defined by Harbaugh and Merriam (1968), is calculated by least-squares fitting of a two-dimensional polynomial function to a set of spatial data. The residual value is defined as the difference between the observed value for a sampling point and the computed value for that point.

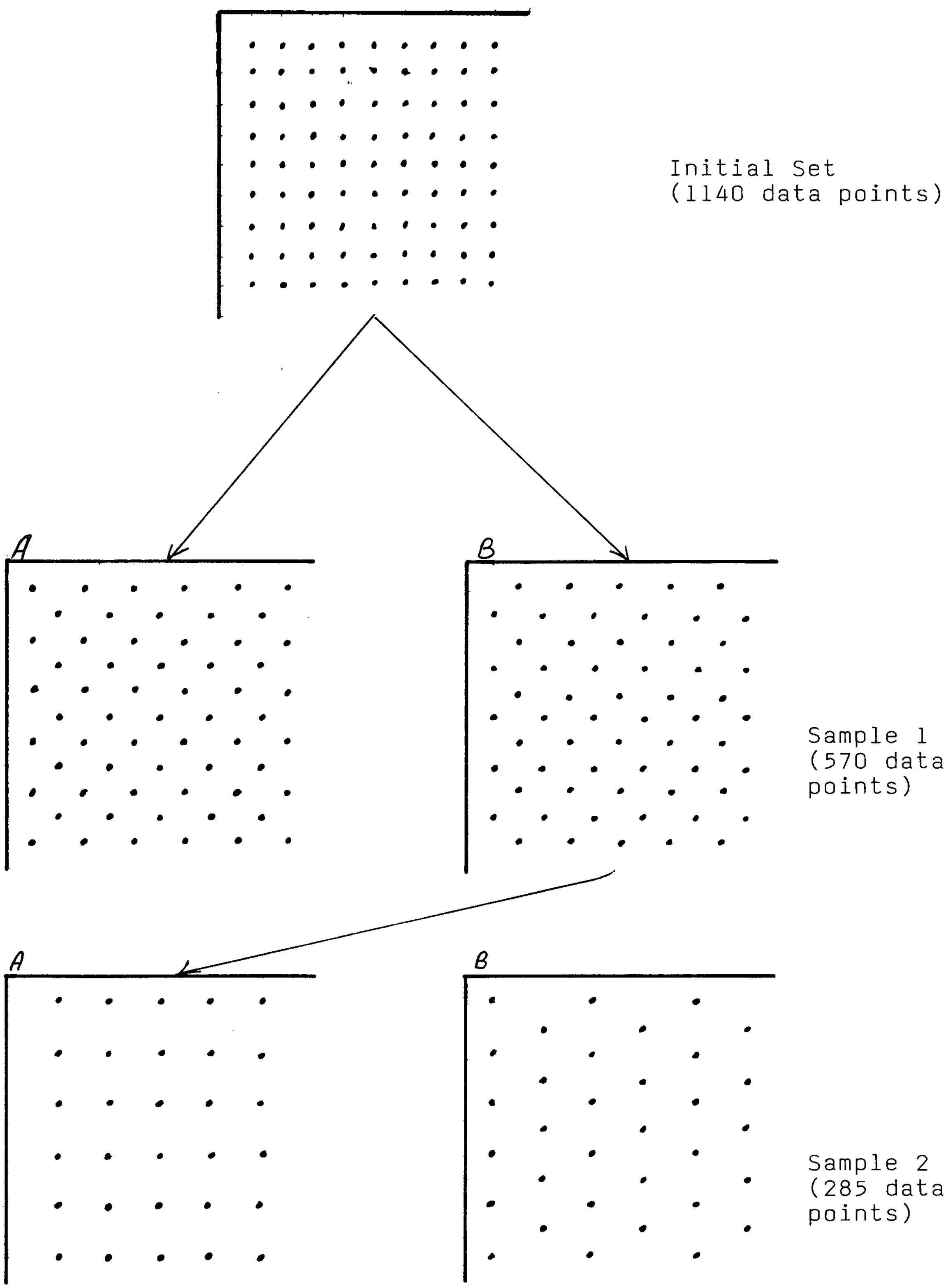

Figure 4. Sampling methods used; dots indicate the data points selected from the initial set.

The residual value may be thought of as a local component, while the trend surface may be viewed as a regional component. The regional trends can therefore be interpreted by analyzing contoured trend surfaces, and local anomalies, such as copper concentrations, can be discerned from contoured residual values.

After the contoured maps of the 4th, 5th, and 6th degree (order) trend surfaces and residuals for copper were plotted, these maps were compared visually to identify the "principal surface" which is defined by Pride and Hasenohr (1983) as the first surface where a persistent trend occurs. In the Bonanza area, the principal surfaces for copper are assumed to be the 6th degree trend surface (Pride and Hasenohr, 1983). Thus the 6th degree trend surface and residual maps are used as a basis of comparison between the initial set and the samplings.

The anomalous residual values for copper, located near the margins of the maps, were viewed carefully because the least-squares technique often introduces spurious anomalies on the edges of the data set. The marginal highs do not necessarily indicate anomalous copper concentrations; therefore, marginal effects have been ignored in this investigation.

The results and interpretations of the principal surfaces of the sampling methods have been combined; sampling methods 1A and 1B are described and interpreted as method 1, and sampling methods 2A and 2B are described and interpreted as method 2.

RESULTS AND INTERPRETATIONS

The 6th degree trend surface (principal trend surface) and the positive residuals (Figures 5 and 6) for the initial data set show a high positive copper anomaly along the northeastern margin of the caldera. This high probably reflects known surface mineralization in the area, and it also may reflect the presence of a concealed ring-type intrusion. Bends in the contour lines of the trend surface (Figure 5) also outline the southeastern margin of the caldera, and may be associated with mineralization and ring-type intrusions in the southern mineral district. A positive residual high in the eastern part of the map (Figure 6) may be ignored since it is located over a body of gabbro, which does not appear to pertain to the mineralization and alteration of the caldera.

The principal trend surfaces for method 1 (Figures 7 and 9), which utilizes one-half of the data samples of the initial set, exhibits a regional high in the northeastern corner of the caldera, plus the bends of the contour lines form a crude outline of the southeastern portion of the caldera, like those in the initial set (Figure 5). The residual high in the northeastern portion of the caldera in the initial set is found in both sampling methods 1A and 1B (Figures 8 and 10); however, the residual high in sampling method 1A (Figure 8) has a much greater magnitude as compared to the initial set (Figure 6) and to sampling method 1B (Figure 10). In summary, method 1 can be interpreted as similar to the initial set that relates the

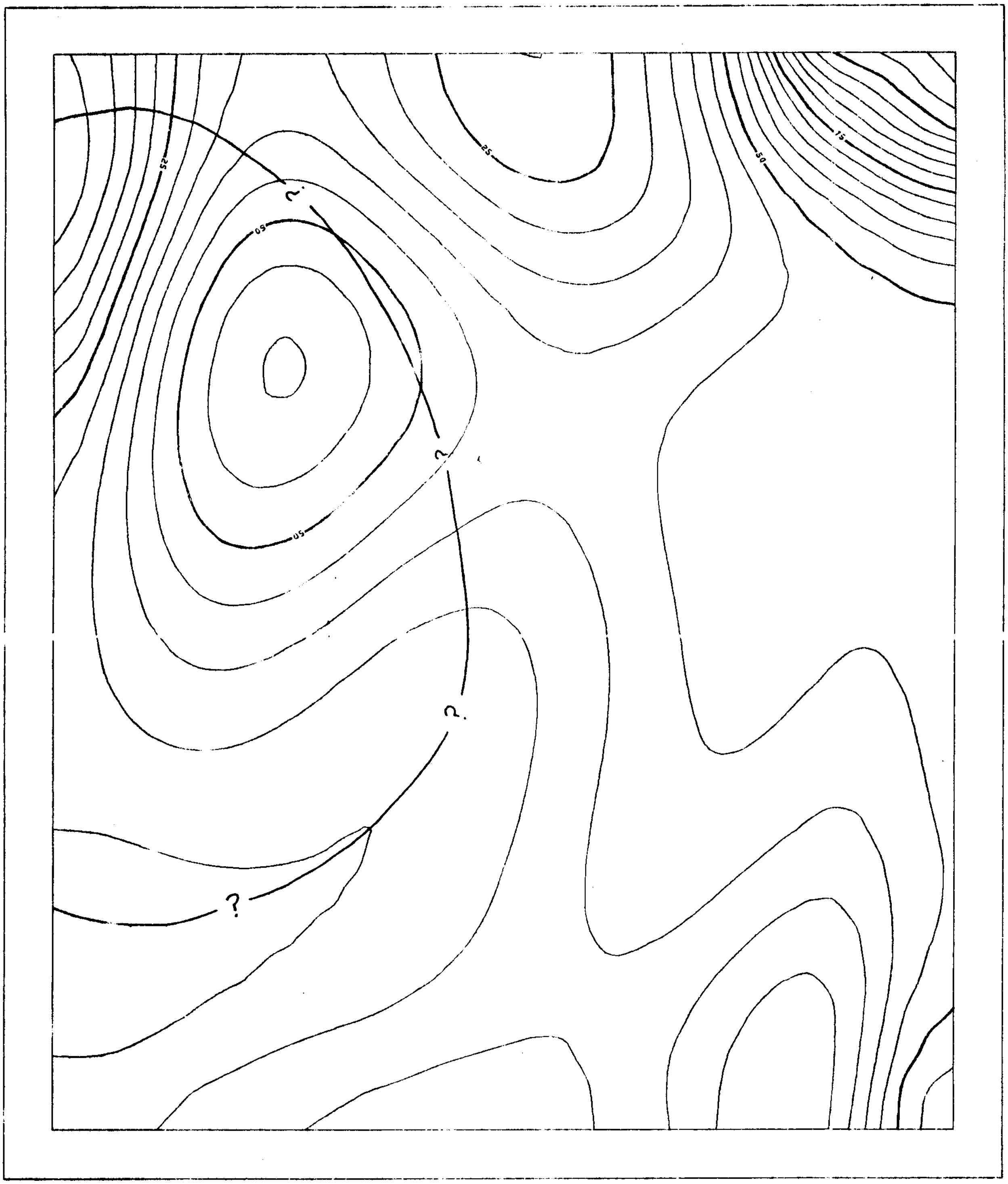

Figure 5. 6th degree trend surface for copper for the Bonanza area (Initial Set). Note that the caldera is in the western portion of the map and that the map is oriented so that north is towards the top of the page.

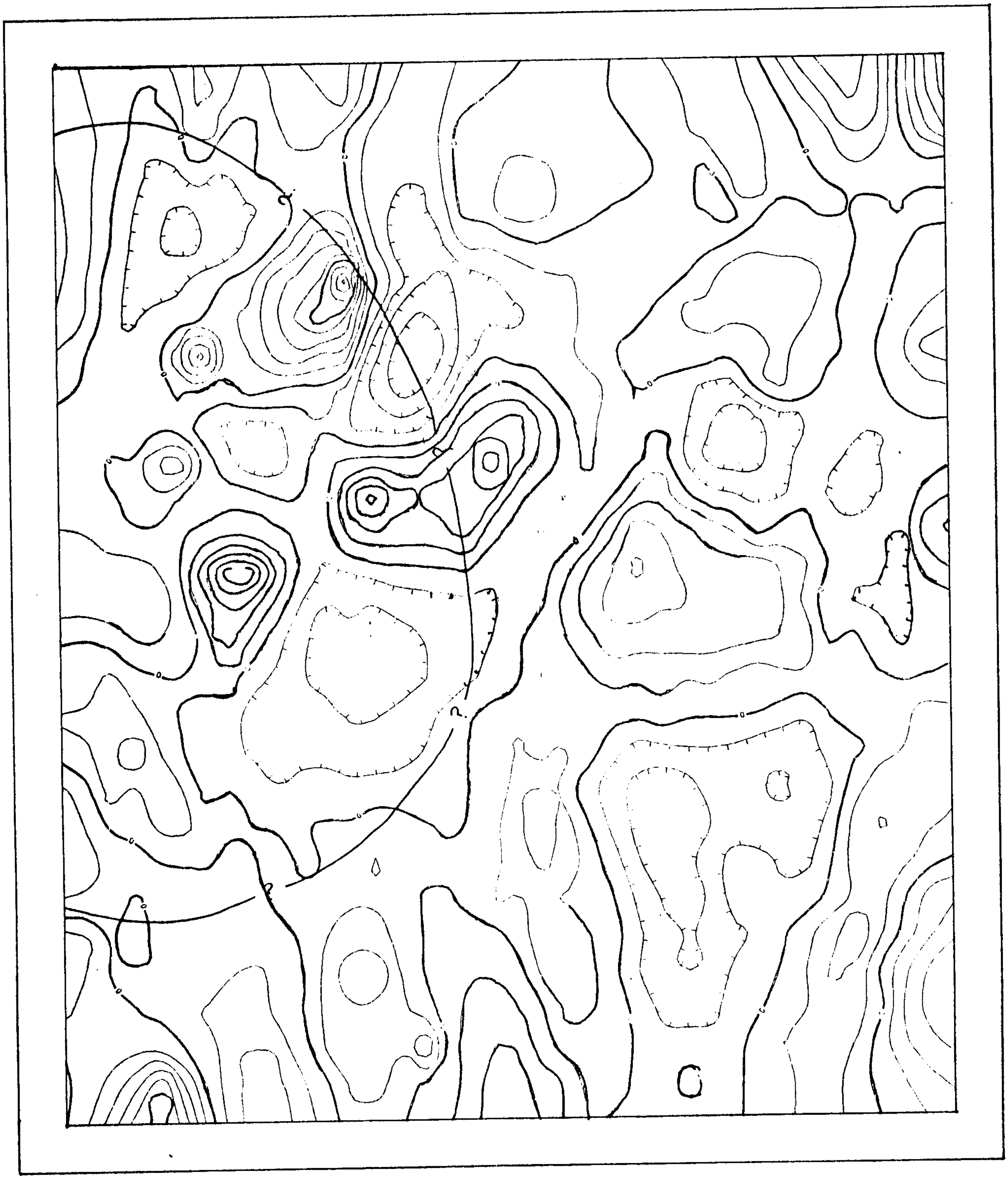

Figure 6. 6th degree residuals for copper for the Bonanza area (Initial Set).

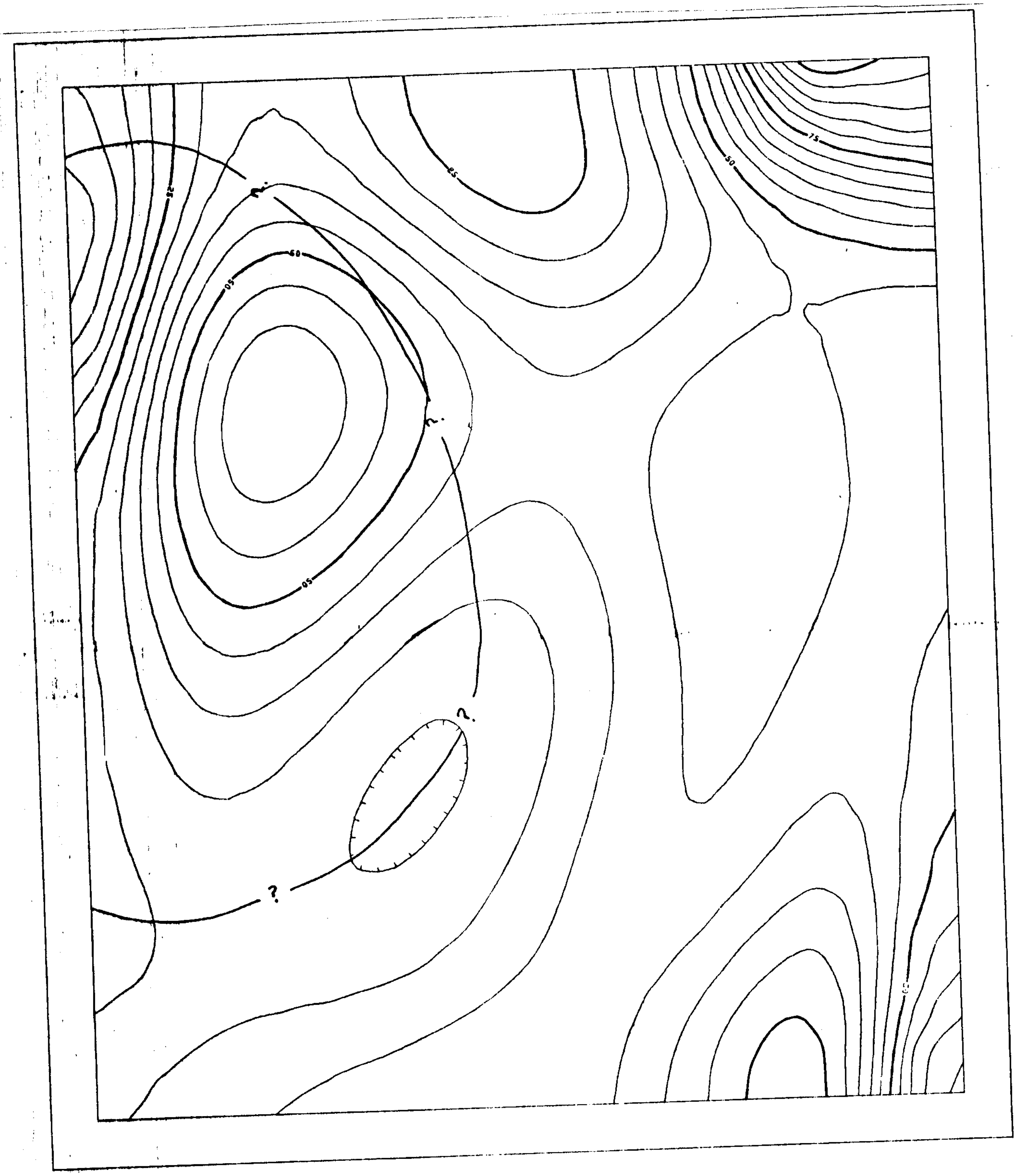

Figure 7. 6th degree trend surface for copper for the Bonanza area (Sampling Method 1A).

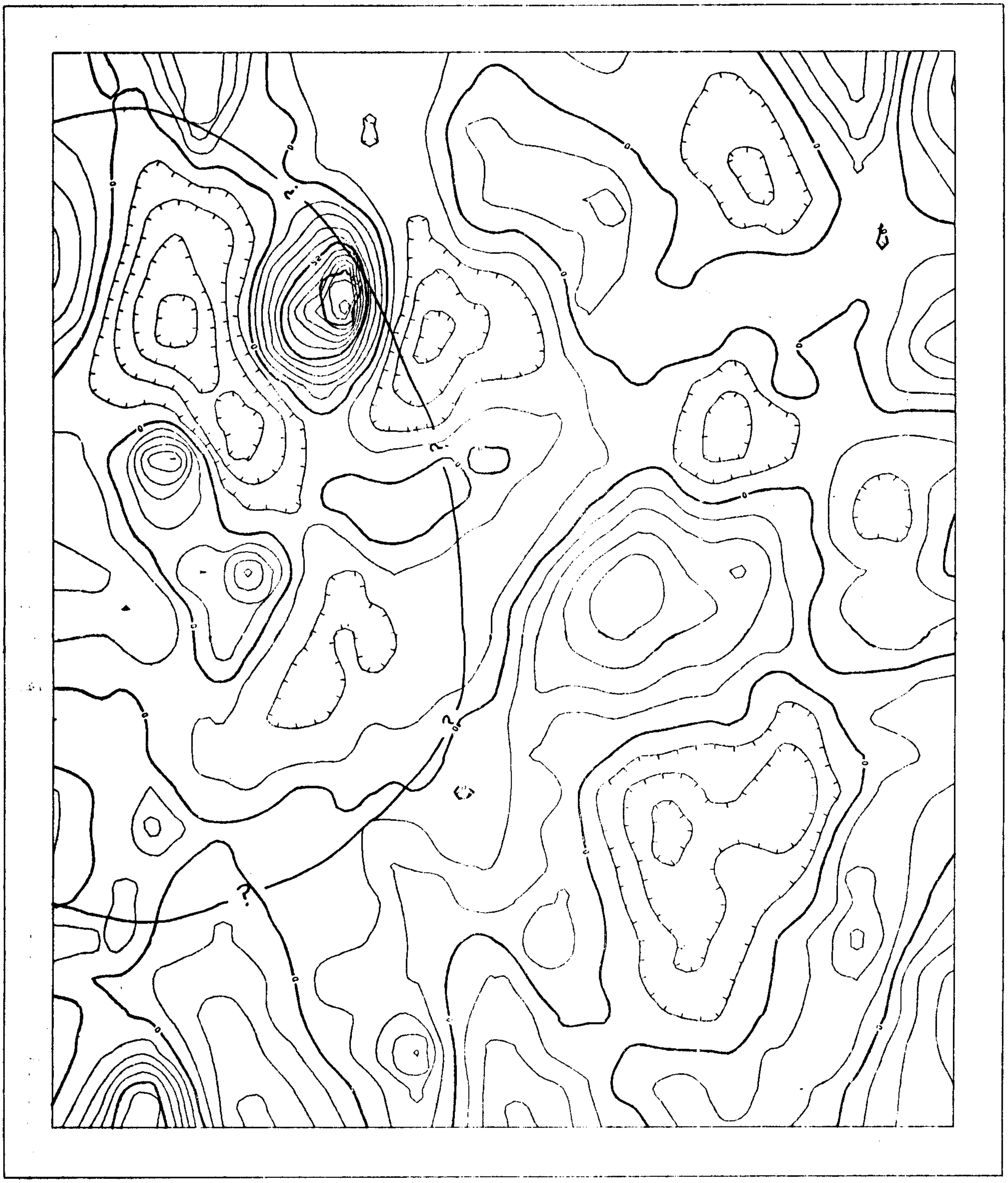

Figure 8. 6th degree residuals for copper for the Bonanza area (Sampling Method 1A).

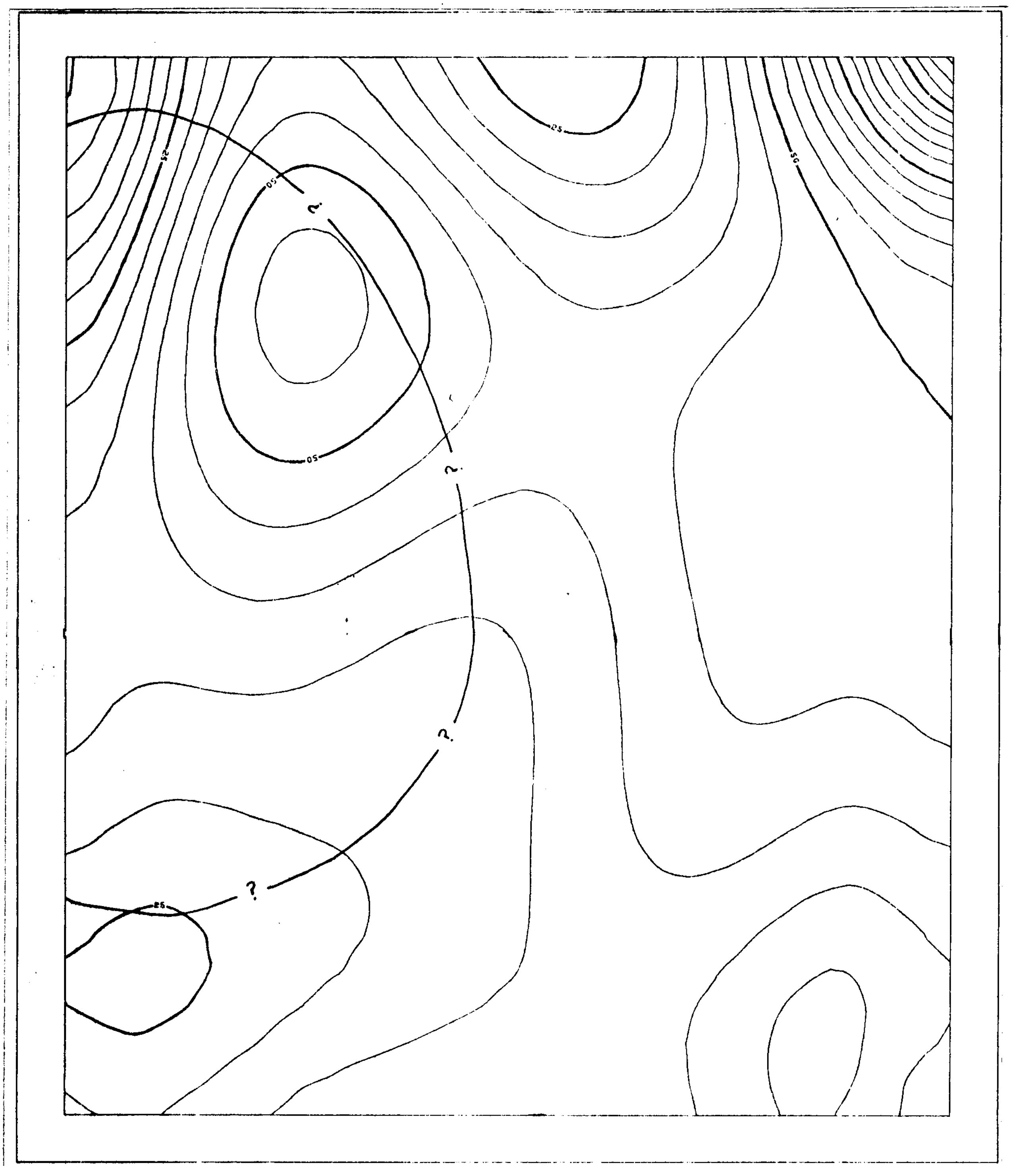

Figure 9. 6th degree trend surface for copper for the Bonanza area (Sampling Method 1B).

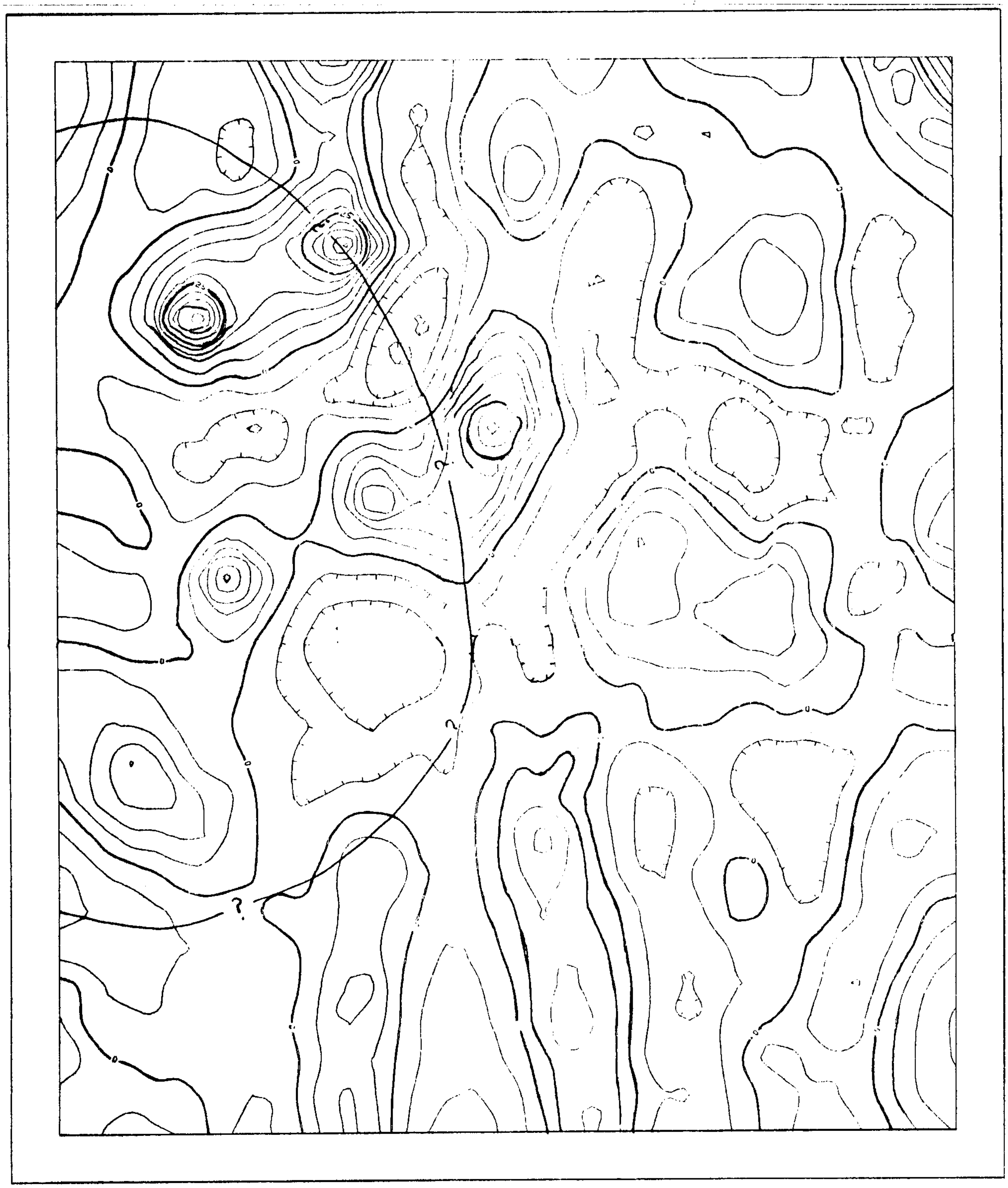

Figure 10. 6th degree residuals for copper for the Bonanza area (Sampling Method 1B).

locations and trends of copper to the mineralization and to the geology of the caldera.

Method 2, which uses one-quarter of the data samples of the initial set, has several similarities to both method 1 and the initial set. Regional highs (Figures 11 and 13) also are located along the northeastern margin of the caldera, and bends of the contour lines of the trend surfaces form a crude outlining of the southeastern portion of the caldera. The positive residual highs also are similar to those in the initial set, and it is worth noting that the positive residual map of sampling method 2A (Figure 12) shows a remarkable similarity to the positive residual map of the initial set (Figure 6). In summary, method 2, like method 1, has residuals that are similar to those of the initial set that relates the locations and trends of copper to the mineralization and to ring-type intrusive activity in the Bonanza mineral district.

A summary of the principal trend surface highs for the initial set and sampling methods 1A, 1B, 2A, and 2B is presented (Figure 15). It is interesting to note the proximity of the highs in the northeastern area of the caldera, which corresponds to the northern mineral district. The high east of the caldera margin, noted in method 2B, lies over the Turquessa Gabbro (Figure 2).

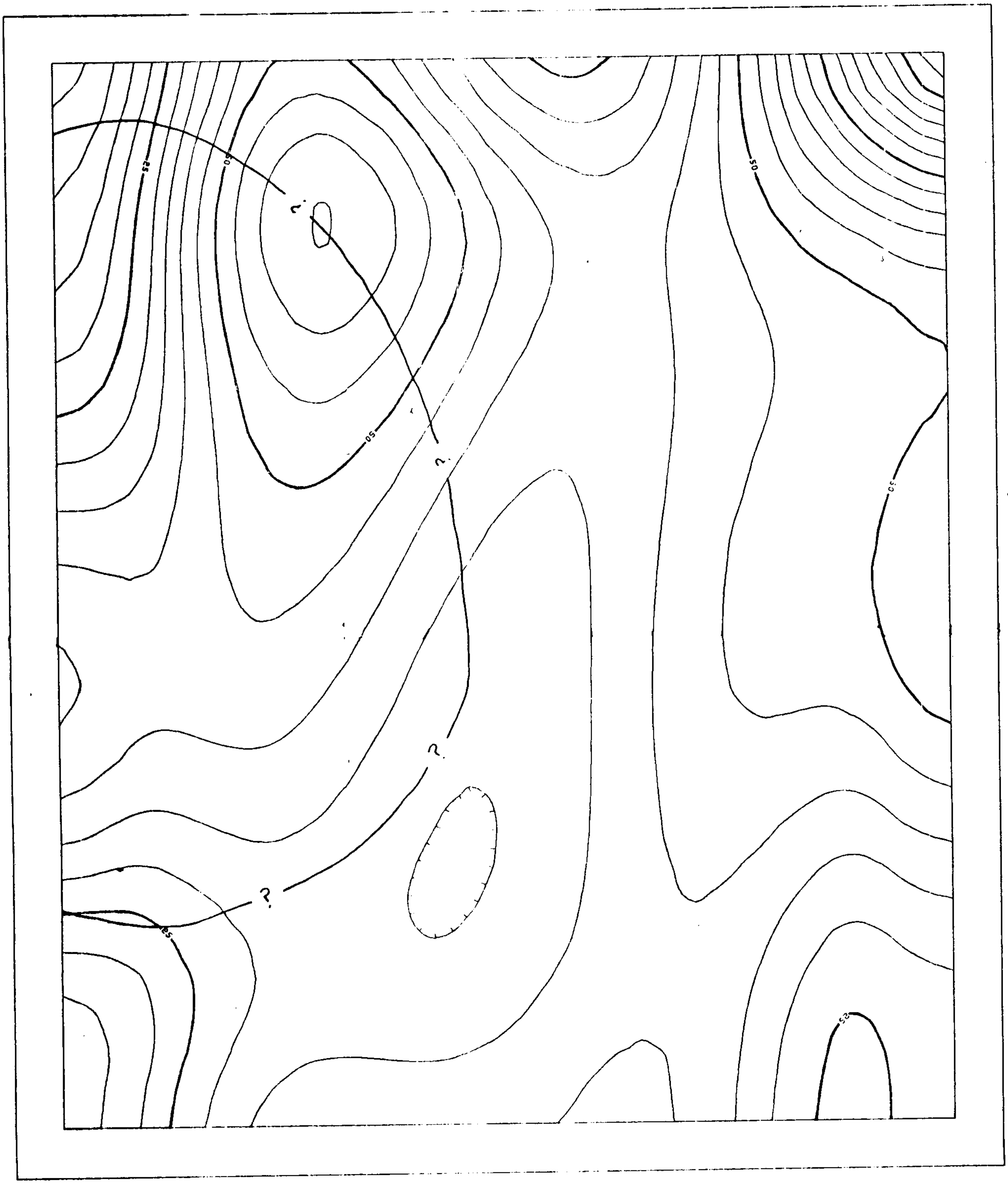

Figure 11. 6th degree trend surface for copper for the Bonanza area (Sampling Method 2A).

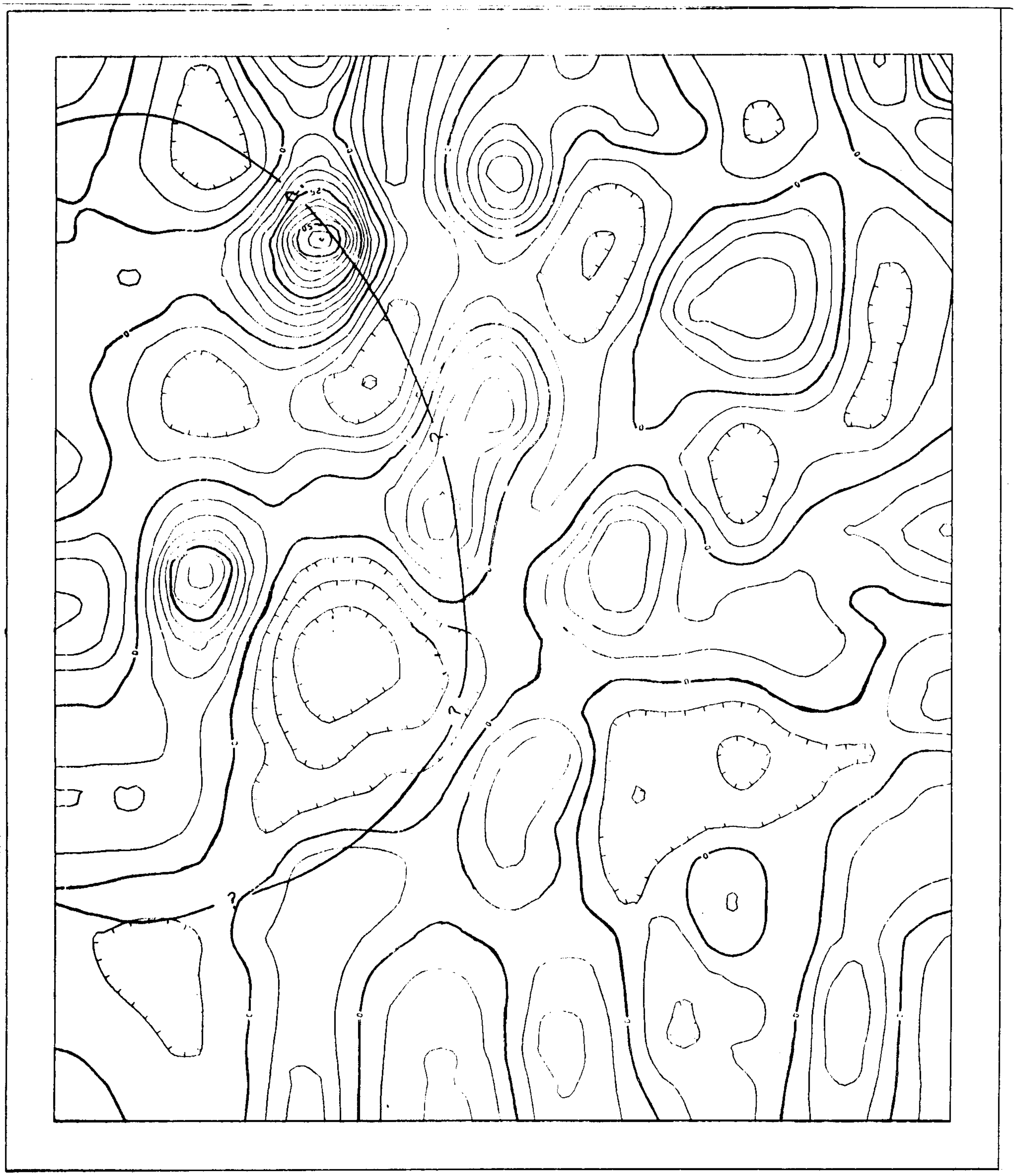

Figure 12. 6th degree residuals for copper for the Bonanza area (Sampling Method 2A).

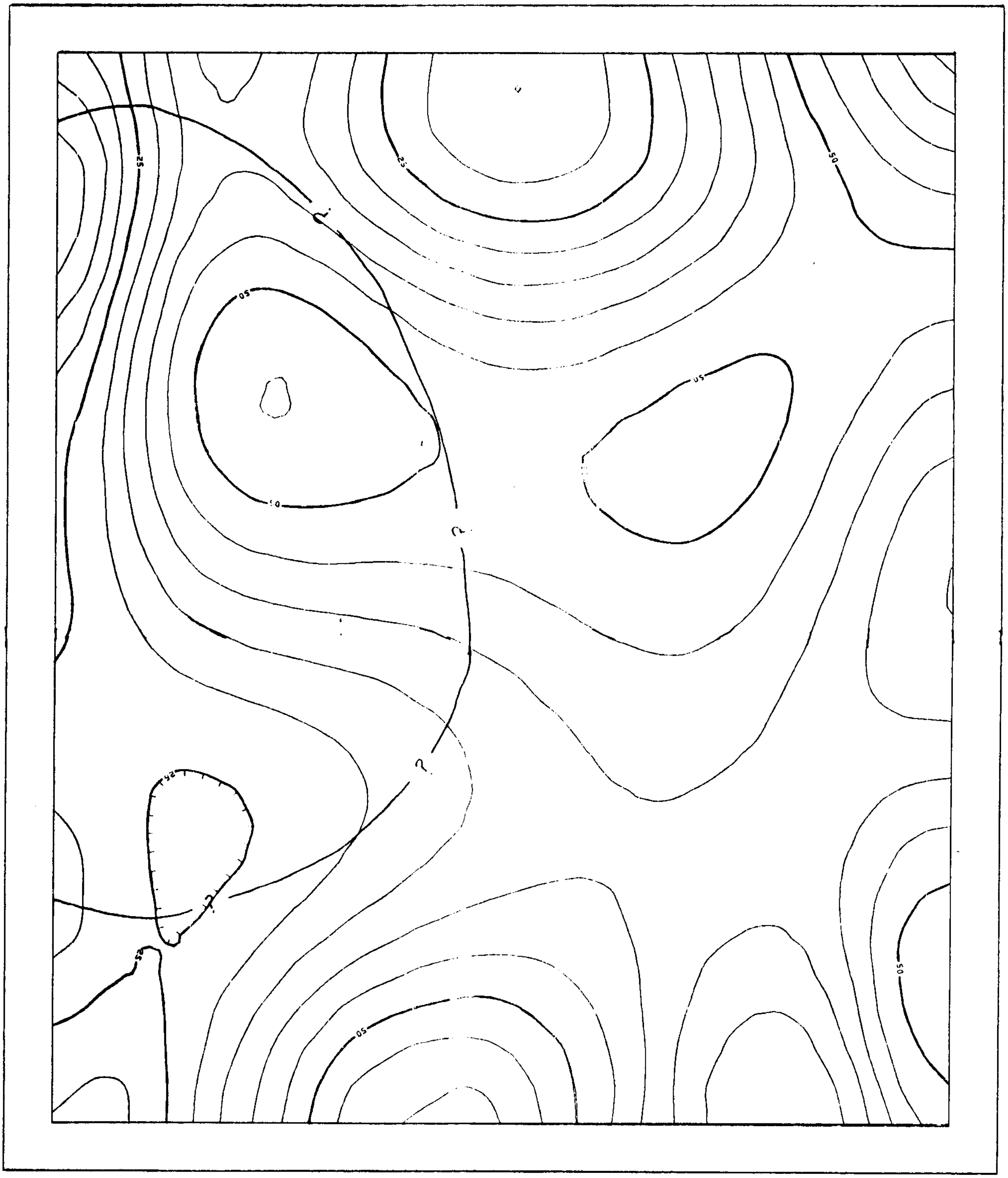

Figure 13. 6th degree trend surface for copper for the Bonanza area (Sampling Method 2B).

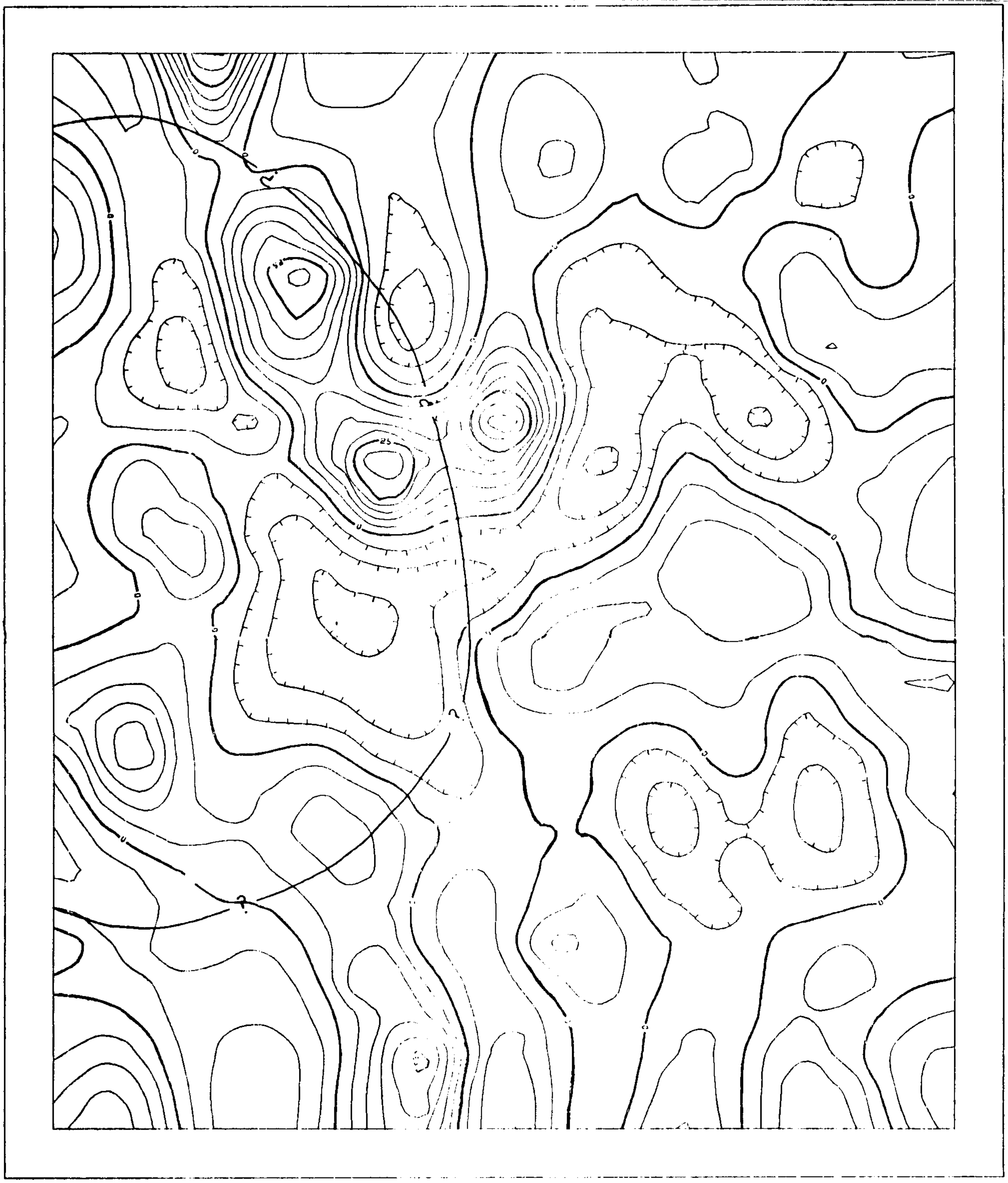

Figure 14. 6th degree residuals for copper for the Bonanza area (Sampling Method 2B).

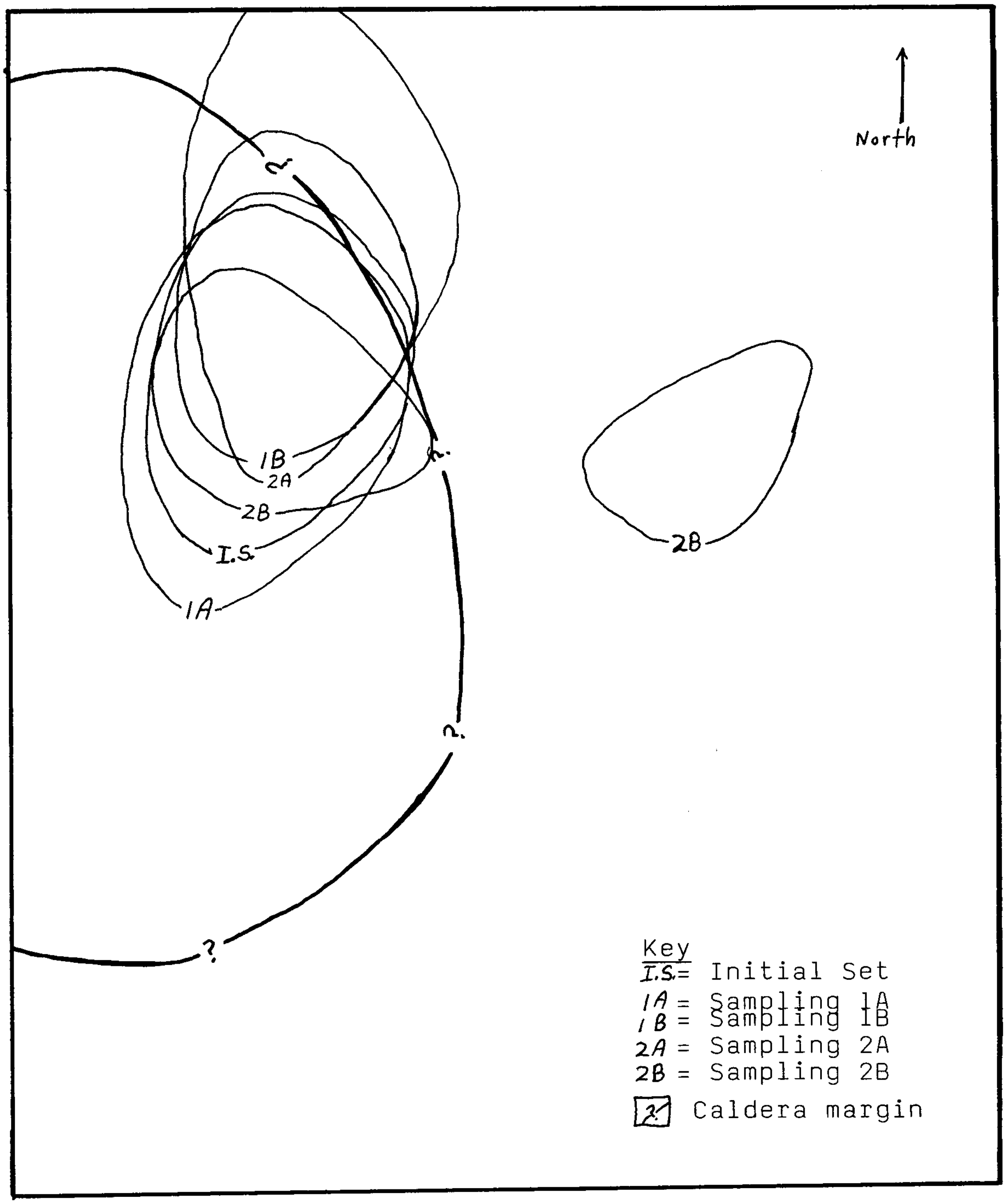

Figure 15. 6th degree trend surface highs for copper superimposed onto one map for comparative purposes.

CONCLUSIONS

The principal trend surface and the positive residual maps for methods using one-half and one-quarter of the sampling points in the initial set correlates well with the geology of the Bonanza caldera and with the location of copper concentrations in the district. An anomalous concentration of copper is located along the northeastern margin of the Bonanza caldera and is related to the northern mineral district and to the possible existance of a concealed, ring-type, felsic intrusion. The principal trend surfaces show an outline of the southeastern margin of the caldera which may correspond to mineralization and ring-type intrusive activity and/or fracturing in the southern mineral district. The number of data points used by Pride and Hasenohr could have been reduced to at least one-quarter of the number used in their study, and the locations of significant copper concentrations in the district still would have been apparent.

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Program NOSORT

```
// JOB
/*JOBPARM LINES=2000
// EXEC FORTVCG
//FORT.SYSIN DD *
      DIMENSION X(30,38),Y(30,38),Z(30,38),XX(1140),YY(1140),
     *ZZ(1140),ITS(6),COEF(6,91),VAL(6,1140),RES(6,1140),E(6,5),
     *NSTA(30,38),NNSTA(1140)
C
      DO 10 I=1,6
   10    ITS(I)=I
      READ(5,100)((NSTA(I,J),X(I,J),Y(I,J),Z(I,J),I=1,30),J=1,38)
  100 FORMAT(I4,10X,2F7.3/20X,F4.0)
C     NO SORT
      K=1
      DO 20 J=1,38
         DO 20 I=1,30
            XX(K)=X(I,J)
            YY(K)=Y(I,J)
            ZZ(K)=Z(I,J)
            NNSTA(K)=NSTA(I,J)
   20       K=K+1
      NS=K-1
      CALL TREND(NS,XX,YY,ZZ,ITS,COEF,VAL,RES,E,IERROR)
      IF(IERROR.NE.0)GO TO 900
      WRITE(6,101)
  101 FORMAT('1'/(' ',10(E10.4,2X)))
      DO 30 J=1,NS
         IF(MOD(J,50).EQ.1)WRITE(6,102)
      IROW=J/30+1
      IF(MOD(J,30).EQ.1)WRITE(6,105)IROW
  105 FORMAT('0','ROW',I3)
  102    FORMAT('1','TREND SURFACE DATA FOR COPPER'/11X,
     *   '1ST DEGREE',8X,'2ND DEGREE',8X,'3RD DEGREE',8X,'4TH DEGF
     *   ,8X,'5TH DEGREE',8X,'6TH DEGREE'/5X,6(4X,'TREND',
     *   4X,'RESID'))
   30 WRITE(6,103)NNSTA(J),(VAL(I,J),RES(I,J),I=1,6)
  103 FORMAT(' ',I4,12F9.2)
      STOP
  900 WRITE(6,104)IERROR
  104 FORMAT(' ','ERROR OCCURS IN TREND PROGRAM OF CEC',5X,I1)
      STOP
      END
      SUBROUTINE TREND (N,X,Y,Z,ITS,COEF,VAL,RES,E,IERROR)
      DIMENSION X(N),Y(N),Z(N),ITS(6),IP(92),COEF(6,91),VAL(6,N),
     1 RES(6,N),E(6,5)
      DOUBLE PRECISION S(91,92),T(91,92),U(91)
      M=MAXO(ITS(1),ITS(2),ITS(3),ITS(4),ITS(5),ITS(6))
      IF(M.LT.1.OR.M.GT.12)GO TO 110
      NN=((M+1)*(M+2))/2
      IF(N.LT.NN)GO TO 120
      NN1=NN+1
      DO 10 I=1,NN
      DO 10 J=I,NN1
   10 T(I,J)=0.
      SUM=0.
      DO 20 L=1,N
      SUM=SUM+Z(L)
      CALL UGEN(X(L),Y(L),U,M)
      DO 20 I=1,NN
```

```
      T(I,NN1)=T(I,NN1)+U(I)*Z(L)
      DO 20 J=I,NN
20    T(I,J)=T(I,J)+U(I)*U(J)
      DO 30 I=2,NN
      LU=I-1
      DO 30 J=1,LU
30    T(I,J)=T(J,I)
      ZM=SUM/FLOAT(N)
      V=0.
      DO 40 L=1,N
40    V=V+(Z(L)-ZM)**2
      IF(V.EQ.0.)GO TO 130
      DO 100 K=1,6
      IF(ITS(K).EQ.0)GO TO 100
      NC=((ITS(K)+1)*(ITS(K)+2))/2
      NC1=NC+1
      DO 60 I=1,NC
      S(I,NC1)=T(I,NN1)
      DO 60 J=1,NC
60    S(I,J)=T(I,J)
      CALL EQUATS (S,NC,NC1,IP)
      IF(IP(NC1).GT.0)GO TO 140
      DO 70 I=1,NC
70    COEF(K,I)=S(I,1)
      E(K,1)=0.
      DO 90 L=1,N
      CALL UGEN(X(L),Y(L),U,ITS(K))
      VAL(K,L)=0.
      DO 80 I=1,NC
80    VAL(K,L)=VAL(K,L)+U(I)*S(I,1)
      RES(K,L)=Z(L)-VAL(K,L)
90    E(K,1)=E(K,1)+RES(K,L)**2
      E(K,2)=V-E(K,1)
      E(K,3)=E(K,2)/V
      E(K,4)=SQRT(ABS(E(K,3)))
      IF(E(K,3).LT.0.)E(K,4)=-E(K,4)
      E(K,5)=SQRT(E(K,1)/FLOAT(N))
100   CONTINUE
      IERROR=0
      GO TO 150
110   IERROR=1
      GO TO 150
120   IERROR=2
      GO TO 150
130   IERROR=3
      GO TO 150
140   IERROR=4
150   RETURN
      END
      SUBROUTINE UGEN(X,Y,U,M)
      DOUBLE PRECISION U(91)
      U(1)=1.
      IC=1
      DO 20 KK=1,12
      IF((M-KK).LT.0)GOTO30
      LU=IC+KK-1
      DO 10 IK=IC,LU
      KU=IK+KK+1
10    U(KU)=U(IK)*Y
      U(LU+1)=U(IC)*X
```

```
 20   IC=IC+KK
 30   RETURN
      END
      SUBROUTINE EQUATS(A,N,M,IP)
      DOUBLE PRECISION A(91,92),S,T
      INTEGER IP(92)
      L=N-1
      DO 10 I=1,N
 10   IP(I)=I
      IP(M)=0
      DO 23 K=1,L
      KA=K+1
      S=0.D0
      DO 12 I=K,N
      DO 12 J=K,N
      T=DABS(A(I,J))
      IF(T-S)12,12,11
 11   S=T
      JZ=J
      IZ=I
 12   CONTINUE
      IF(S)24,24,13
 13   IF(IZ-K)14,16,14
 14   DO 15 J=K,M
      S=A(IZ,J)
      A(IZ,J)=A(K,J)
 15   A(K,J)=S
 16   IF(JZ-K)17,19,17
 17   DO 18 I=1,N
      S=A(I,JZ)
      A(I,JZ)=A(I,K)
 18   A(I,K)=S
      IS=IP(JZ)
      IP(JZ)=IP(K)
      IP(K)=IS
 19   DO 20 J=KA,M
 20   A(K,J)=A(K,J)/A(K,K)
      DO 23 I=KA,N
      IF(A(I,K))21,23,21
 21   DO 22 J=KA,M
 22   A(I,J)=A(I,J)/A(I,K)-A(K,J)
 23   CONTINUE
      IF(A(N,N))25,24,25
 24   IP(M)=1
      GO TO 28
 25   A(N,M)=A(N,M)/A(N,N)
      DO 26 K=2,N
      IZ=M-K
      DO 26 I=1,IZ
 26   A(I,M)=A(I,M)-A(I,IZ+1)*A(IZ+1,M)
      DO 27 K=1,N
      IZ=IP(K)
 27   A(IZ,1)=A(K,M)
 28   RETURN
      END
/*
//GO.SYSIN DD *
```

APPENDIX A

The following changes were used to produce sampling methods 1A and 1B:

```
13.     C     SAMPLING METHOD 1A

15.1          IA=1
15.2          IF(MOD(J,2).EQ.0)IA=2
15.3          DO 20 I=IA,30,2
```

```
13.     C     SAMPLING METHOD 1B

15.1          IA=2
15.2          IF(MOD(J,2).EQ.0)IA=1
15.3          DO 20 I=IA,30,2
```

APPENDIX B

SURFACE II SAMPLE PROGRAM

```
// JOB ,
// REGION=512K
/*JOBPARM LINES=5000
// EXEC SURF2V,SIZE=40K
//GO.SYSIN  DD  *
TITL 6TH DEGREE TREND SURFACE FOR CU
DEVI 5,'MEYER,W.'
IDXY 570,11,3,1,2,3.0,0,0,,'(4X,2F7.3,40X,F8.2)'
GRID 0,15,19
NEAR 2,8,2.5,3.75
EXTR
BXEX ,,,,0.25,0.25,0.25,0.25
CONT 1,1
CINT 0,0.5,0.5,0.06,0,,5
MSMO 1,1,2,3,3
SIZC 1,11.25,9.25
PERF
STOP
/*
//GO.FT11F001  DD  DISP=SHR,DSN=TS5196.COPPER
//
```